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Physical characterization of commercial woodchips on the Italian energy market

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ABSTRACT

The Authors set out to determine the particle-size distribution, the fiber and bark content, and the heating value of a wide sample of wood chips, collected from 60 commercial biomass terminals active in Northern Italy. This sample was meant to represent a cross-section of the Italian fuel chip market, and focused on four main feedstock types: sawmill residues, logging residues, small trees and short rotation coppice (SRC). Overall, the Authors collected 300 samples, each weighing approximately 1 kg. Particle-size distribution was determined with an automatic screening device on 210 samples, according to European Standard CEN/TS 15149-1. All samples were also manually separated into the following main components: fiber, bark, twigs, leaves, dust and other. The higher heating value (HHV) was determined on 56 one-gram subsamples using an adiabatic bomb calorimeter. Sawmill residues and small trees offered the best quality, with high fiber content (85–90%) and favorable particle-size distribution. On the contrary, both logging residues and SRC presented a high bark content ($\geqslant$20%) and occasionally a mediocre particle-size distribution, being often too rich in fines ($\geqslant$10%). These problems were especially serious with fuel derived from 1-year old SRC sprouts. There is a need for reducing the supply cost of small trees, and improving the quality of SRC biomass.

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1. Introduction

The versatile nature of wood biomass fuels is a main asset and a significant obstacle at the same time. On one hand, wood biomass is available in many forms and in all parts of the world, allowing the deployment of bioenergy almost everywhere, once the main sources have been identified and assessed [2]. On the other hand, this diversity makes biomass a complex and difficult fuel [24]. Different sources will produce fuel types with different quality characteristics, which will affect the choice and the performance of the conversion technology [4], as well as the potential for co-firing [33]. Wood fuel characteristics have a significant impact on the yield, quality and stability of both syngas [40] and pyrolysis oil [9]. Although particularly efficient [41], the newest small scale gasification technologies are especially sensitive to wood fuel characteristics [21], as demonstrated by the unfortunate failure of the ARBRE project, also related to technical problems with the available local fuels [39]. Even if one remained within the narrow boundaries of forest fuels, woodland management will offer a mix of different fuels types, such as logging residues, offcuts, slovens and timber [25]. In fact, the quality of the fuel will vary according to site characteristics, harvesting season and silvicultural treatment [10]. Nor can one think about targeting a single fuel source with a specific management practice in order to standardize fuel quality, because the growing demand for wood fuels must be matched by an expanding supply, in order to guarantee price stability [14]. This is crucial to the development of the biomass energy sector, where fuel represents a major cost item [19]. Within this context, some experts advocate the development of quality labels for both conversion units and the respective fuel types [53], also with the purpose of facilitating the growing cross-border trade-flows [8]. Hence the interest in determining the relationship between the origin of the wood fuel and such main quality characteristics as: particle-size distribution, bark content and calorific value. Particle-size distribution is crucial to fuel handling efficiency [17], to its drying and reaction rate [30], to the energy required for conversion into ethanol [16], and to the yield of bio-oil obtained from pyrolysis [47]. Bark has a high ash and alkali metal content, which causes corrosion and sintering of the boilers [52], although the ash content in tree bark is 4–5 times lower than in straw and other herbaceous crops [37,56]. A high bark to fiber ratio has a crucial [46] and negative effect on pulping [38], as well as on heating value [23] – the latter related to the higher moisture content of bark compared to fiber. A high bark content also has a significant impact on pelletizing potential [28] and pellet durability [27]. Calorific value is an essential quality for any fuels, and is relatively constant for wood fuels in their dry status [7]. In this respect,

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moisture content is the most important physical characteristic of wood fuels, but it depends on a number of factors often independent from the original source of the raw material, so that it may be relatively difficult to relate feedstock type with moisture content. Against this background, the Italian National Council for Research (CNR) set out to determine the particle-size, the fiber and bark content, and the heating value of a wide sample of wood chips, collected from commercial biomass operations active in Northern Italy. This sample was meant to represent a cross-section of the Italian fuel chip market, and the expected large variability caused the exclusion of moisture content from the analysis, on the assumption that moisture content would be affected by a number of different parameters independent from feed stock type and origin, and related to other factors, such as: season of harvest, handling technique, storage mode and duration. The analysis focused on four main feedstock types: sawmill residues, logging residues, small trees and short rotation coppice (SRC).

2. Materials and methods

The authors sampled 60 different chipping terminals in Northern Italy, collecting five samples from each, for a total of 300 samples. Each sample consisted of approximately 1 kg of chips, which were put in individual bags, duly tagged in order to identify the type and provenance of each sample. Sampling aimed at providing a representative cross-section of current operations and did not follow a specific design to balance treatments for comparative purposes. In fact, treatments were categorized after the initial sampling, by grouping samples with similar characteristics. In particular, the following 6 groups were identified: broadleaved logging residues, conifer logging residues, broadleaved small trees, conifer small trees, sawmill residues (always conifer) and short rotation coppice, the latter always consisting of a broadleaved species such as poplar. Logging residues consisted of tops and branches, left after the harvesting of adult trees from regeneration cuts. Small trees were obtained from the thinning of young stands, or from the regeneration cuts of conventional coppice forests, very common in Italy and harvested at 15–30 years rotations. No categorization was done for chipping method and machine, because such information was unavailable for most samples. This may introduce an unaccounted source of variation, as chipper characteristics have been shown to significantly affect particle-size distribution [48]. However, it was possible to verify that all samples had been processed with chippers – not grinders – and that the majority of chippers were industrial drum units. Only short rotation coppice had been comminuted with a different device, and namely a modified forage chopper drum. In the absence of information about chipper type and of a balanced design, eventual comparisons are considered indicative not conclusive, and are analyzed for indications of trends.

The samples were analysed for (a) component breakdown, (b) particle-size distribution and (c) higher heating value (HHV). For economy, most work was devoted to component breakdown, which was the most original element of the study. Determination of particle-size distribution and HHV was conducted respectively on 210 and 56 samples, randomly extracted from the larger pool of original samples.

Component breakdown was determined on 100 g subsamples, by manually separating their content into the following main components: fiber, bark, twigs, leaves, dust and other. Each component was weighed with a Mettler precision scale.

Particle-size distribution was determined on 500 g subsamples, according to the European Standard, CEN/TS 15149-1:2006 “Solid biofuels – Methods for the determination of particle-size distribution – Part 1: oscillating screen method”, using a certified automatic screening device model FTL0200. Five sieves were used in order to separate the six following chip length classes: >100 mm, 100–63 mm, 63–45 mm, 45–16 mm, 16–3 mm, <3 mm. Each fraction was then weighed with a precision scale.

Higher heating value (HHV) was determined on one-gram subsamples [55] according to the European Standard CEN/TS 14918. Subsamples were ground with a rotating-blade Wiley mill and a 0.7 mm sieve, and compressed into one-gram sample pellets with a IKA C21 press. Pellets were burned into a IKA C 400 adiabatic bomb calorimeter. Before starting actual measurements, the calorimeter was checked with 16 individual calibration runs.

Data were analyzed with the Statview advanced statistics software, in order to check the statistical significance of the eventual differences between treatments with ANOVA techniques. Post-hoc tests were conducted with Scheffe’s method, which is considered the most robust against possible violations of the normality assumption [44].

3. Results

Table 1 shows the results obtained for particle-size distribution, determined on 192 of the original 300 samples. As an average, the chips produced in the 60 sampled operations contain almost no oversize particles (>63 mm), and about 8% of fines (<3 mm), which can grow to 26% in the worst case. The average proportion of the accept fraction (63 to 3 mm) is 90%, but it drops to 70% in the worst case. Comparison between treatments allows detecting a statistically significant difference for the conifer residues only, which show the highest proportion of fines and the lowest proportion of accepts. Broadleaved residues have the largest proportion of oversize particles, and this difference is also significant to Scheffe’s post-hoc test, conducted at the 10% significance limit. For the rest, there is no significant difference between treatments.

Table 2 shows the results obtained for fiber content, and conversely for bark and twigs – grouped under a single category, for simplicity. As an average, the chips produced in the 60 sampled operations consist of wood fiber for 82% of their weight, and of bark and twigs for 15%. The remaining weight represents foliage, dust and other contaminants. In the worst case, fiber content can drop to 35% and bark and twigs increase to 51% of the total weight. Post-hoc ANOVA tests allowed gathering the six treatments in three groups, separated by statistically significant differences. Group 1 includes the logging residues – conifer and broadleaved alike – with samples consisting of fiber for 77% of their weight. Group 2 includes small trees and sawmill residues, with a fiber content between 85% and 95% in weight, and a bark and twig content between 8% and 12%. SRC samples represent the third group, characterized by the lowest fiber content and the highest bark and twigs content, respectively estimated to 69% and 27%.

Table 1
Particle size distribution of the chip samples.

Type	Wood	Count, #	Oversize, %	Accepts, %	Fines, %
Residues	Broadleaved	8	**5.4**	88.4	6.2
Residues	Conifer	24	0.2	**86.8**	**12.9**
Small tree	Broadleaved	35	0.4	92.1	7.5
Small Tree	Conifer	71	0.5	92.1	7.4
Sawmill	Conifer	21	0.3	92.3	7.3
SRC	Broadleaved	51	0.9	90.2	8.8
All	All				
	Average	210	0.6	90.8	8.6
	Minimum	210	0.0	70.1	1.0
	Maximum	210	27.9	99.0	26.1

Note: Oversize = particles > 63 mm; Accepts = particles from 63 to 3 mm; Fines = particles < 3 mm; values in bold represent a difference between treatments (more rows in the same column) that resulted significant to Scheffe’s post-hoc test, conducted at the 10% significance limit.

Table 2
Fiber and Bark & Twig content of the chip samples.

Type	Wood	Count, #	Fiber, %	Bark & Twigs, %	Other, %	Group, #
Residues	Broadleaved	16	77.4	20.8	1.8	1
Residues	Conifer	60	77.4	18.8	3.8	1
Small Tree	Broadleaved	51	85.2	12.0	2.8	2
Small Tree	Conifer	87	88.0	10.0	2.0	2
Sawmill	Conifer	35	90.3	8.6	1.1	2
SRC	Broadleaved	51	69.1	26.6	4.3	3
All	All					
	Average	300	81.9	15.4	2.7	
	Minimum	300	35.3	0.0	0.0	
	Maximum	300	100.0	50.8	13.9	

Note: Groups represent treatments with no significant differences among them, but significantly different from those in the other groups, according to Scheffe's post-hoc test, conducted at the 10% significance limit; "other" includes dust, foliage and other materials.

The results of the calorimetric tests are reported in Table 3. There is no significant difference between tree components (fiber and bark), and the only significant difference is between broadleaved and conifer species, the latter significantly richer in higher heating value.

Finally, Table 4 shows the results for the SRC samples only, with the purpose of checking the eventual relationships between chip quality and rotation age. This was done in order to determine if the new trend towards extended rotation has the objective justification of a better product quality, as claimed by growers [26]. Samples obtained from plantations managed according to 1-year rotations contain a significantly lower proportion of fiber, compared to the samples obtained from older plantations. Concerning particle-size, the comparison between treatments is only valid for 1-year and 2-year rotations, which are normally harvested with the same machine type, namely with a modified forage harvester [49]. Five-year rotations do offer a better particle-size distribution especially with respect to the lower incidence of fines, but this result could be related to the use of a standard forestry chipper, adopting a radically different comminution device compared to the modified forage harvester.

Table 3
Higher heating value for fiber and bark & twig.

Treatment	Count, #	Fiber, MJ kg^{-1}	Bark & Twigs, MJ kg^{-1}
Broadleaved	11	19.4	19.1
Conifer	17	**20.2**	**20.3**
SRC	28	19.0	19.0

Note: Values in bold represent a difference between treatments (more rows in the same column) that resulted significant to Scheffe's post-hoc test, conducted at the 10% significance limit.

Table 4
Particle size distribution and fiber content of SRC samples as a function of rotation age.

Rotation	Years	1	2	5	Count
Fiber	%	**60.9**	75.3	71.7	51
Bark & Twigs	%	**34.8**	21.2	21.6	51
Other	%	4.3	3.5	6.7	51
Oversize	%	0.2	0.7	1.8	51
Accepts	%	**85.5**	90.8	93.9	51
Fines	%	**14.3**	8.5	4.2	51

Note: Values in bold represent a difference between treatments (more columns in the same row) that resulted significant to ANOVA testing, conducted at the 10% significance limit.

4. Discussion

Particle-size distribution is a function of different variables, and is significantly affected by chipper type [48], blade wear and screen size [35]. That may explain the very limited difference obtained for feedstock type, since our study did not account for the variability caused by the different chippers used for producing the sampled chip lots. Unfortunately, many samples were obtained from stocks deposited at some storage site (landing, terminal or plant wood yard), and it was impossible to determine the type and especially the conditions of all the chippers used for processing the stock being sampled. Nevertheless, it is interesting to notice that significant results were obtained for chips processed from conifer residues, which indicates how the original characteristics of this feedstock type dominate all other effects. Here, the high proportion of fines is likely to depend on the abundant presence of needle material, which tends to pulverize on impact, as already attested by Nati et al. [35]. The higher proportion of fines will logically detract from the proportion of accepts, so that the two phenomena are closely related. On the other hand, the significantly higher proportion of oversize particles found in broadleaved residues should not be accepted without reserve, due to the rather small sample (count = 8) obtained for broadleaved residues.

Bark content is also higher in logging residues – both conifer and broadleaved. Logging residues consist of tops and branches, which have a higher surface to volume ratio compared to stem wood. On the contrary, sawmill residues are generally represented by slabs and offcuts, often obtained after the logs have been debarked. Hence their high fiber content, which makes them the current wood fuel reference in the Alps [51]. This is especially true in Northern Italy, where about 75% of the fuel delivered to the local district heating plants is sourced from sawmill residues, claimed to be cheaper, higher quality (i.e. lower bark content) and easier to purchase compared to forest fuels [45]. The results of this study indicate that good quality may not be an exclusive character of sawmill residues, and that the chipping of whole trees may offer the same quality results. Therefore, the problem with forest fuels is more likely to be related to their high supply cost compared to industrial residues [20], which justifies the R&D efforts towards increasing the efficiency of forest fuel supply chains [18]. Today, only logging residues might be obtained at a competitive cost, but their quality is not competitive unless one decides to renounce some of the low value log products and chip them with the branch material, in order to increase both chipping productivity and chip quality [5]. Both this strategy and the chipping of whole trees may configure as a form of competition with traditional products [31], unless the integrated production of conventional and energy wood may bring into economical reach those forest stands that would be too expensive to harvest if tapped for conventional products only [50]. On the other hand, the expected rapid growth of the biomass sector requires expanding fuel supply beyond the narrow limits of industrial wood residues [54], which are also the main source of raw material for pellet manufacturing [43].

Short rotation wood crops established on surplus agricultural land offer a very effective way to produce biomass for industrial and energy uses [15], while accruing significant environmental benefits normally absent from traditional agriculture [13,42]. Among various cropping systems, short rotation coppice (SRC) seems to best reflect the expectations of farmers, who are used to short return times and generally show little enthusiasm for traditional wood plantations, harvested at 10–30 year intervals [29]. However, the 1-year rotation cropping system most popular in Italy just a few years ago may represent an extreme development offering little overall benefit. First of all, poplar SRC reaches maximum yield later than willow [22], at an age between three and four years [6], which may well represent the optimum rotation age for this crop [3]. Secondly, this study clearly demonstrates that 1-year rotation plantations produce low quality fuel, with a very high bark content and a particle-size distribution excessively rich in fines. Extending the rotation by one year already allows a significant reduction of both fines and bark content, which will drop from 35% to 21%, as already attested by Guidi et al. [12] for poplar, and by Adler et al. [1] for willow. Although this may represent a significant improvement, 2-year rotation SRC wood still remains a mediocre fuel, with an ash content almost ten times higher (2% vs. 0.3%) than the ash content of clean wood fiber, and at the same level obtained for conifer logging residues [36]. Nor does a further increase of rotation age seem to offer a reliable solution, since our study could not bring any statistical evidence for the higher fiber content obtained from 5-year old SRC trees. However, most of the samples came from older plantations, established with different clones than presently available for extended-rotation SRC, so that our results in this respect may be considered preliminary, and may not negate the possibility of future improvements. Of course, extending rotation age will also prolong return times, and may conflict with the expectations of most farmers, who are generally used to quicker returns. At the same time, a 5-year old rotation will not allow for a flexible product strategy, as potentially obtained from older forests [50].

The higher heating value of conifer wood is well attested in the literature [11], and is naturally related to its high resin content [34]. In this respect, the original contribution of our work is not as much in proving something that is already well known, but rather in associating specific energy content figures to specific fiber and bark content figures, so as to allow an accurate determination of fuel energy content through proximate analysis, as already suggested by Erol et al. [7].

5. Conclusions

The Italian fuel chip market taps four main sources, namely: sawmill residues, logging residues, small trees and SRC. Sawmill residues (slovens and offcuts) are the current reference feedstock, offering the best combination of good product quality and low supply cost. Such favorable characteristics are not matched by the other feedstock types. Logging residues such as tops and branches can be obtained at a low cost, but cannot match the same quality specifications; small trees obtained from thinning operation and from the harvesting of traditional coppice stands offer good product quality, but are still too expensive to get; current SRC plantations miss both the quality and the cost [32] targets. Assuming that the availability of sawmill residues cannot be indefinitely expanded and that fuel price cannot increase dramatically, then any further significant growth of the wood energy sector is vitally linked to the capacity of reaching at least one of the following future objectives: (a) reducing the supply cost of small trees; (b) reducing the supply cost and increasing the quality of SRC products; (c) deploying new conversion technologies that can work efficiently with low-grade wood chips.

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